ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPRB035

DEVELOPMENT OF A BEAM WINDOW PROTECTION SYSTEM FOR THE J-PARC LINAC

H. Takahashi†, S. Hatakeyama, Y. Sawabe,
Japan Atomic Energy Agency (JAEA), J-PARC Center, Tokai-mura, Japan
T. Miyao,
High Energy Accelerator Research Organization (KEK), Accelerator Laboratory, Tsukuba, Japan
T. Ishiyama, T. Suzuki,
Mitsubishi Electric System & Service Co., Ltd, Tsukuba, Japan

Abstract

In J-PARC Linac, some beam dumps are used for beam conditioning and study. A beam window is installed in the beam line of the beam dump.

In 2018, a beam study using a 0-degree beam dump in the Linac resulted in damage to the beam window when the beam intensity has exceeded the tolerance. So as not to repeat this experience, it was decided to immediately advance the development of a beam window protection system. The present paper describes the protection system built as an emergency measure and the tests of its performance.

INTRODUCTION

At the J-PARC Linac, beam conditioning and study are performed using beam dumps (BDs). A beam window is installed upstream of the BD along the beam line [1].

This window can accommodate a beam with a current value of 50 mA, length of 100 µs, no-chop, and repetition rate of 2.5 Hz. The use of beams exceeding these tolerances must always be avoided. However, it had been only checked by operator that beam parameter injected to the beam dump was within tolerance or not.

In a 2018 beam study, human error caused the beam to exceed the tolerance for a 0-degree (0-deg) BD, and the beam window was cracked. The beam parameters of this trouble were the beam current of 50 mA, the length of 500 µs and the repetition rate of 25 Hz. While the Linac beam operation could still be performed, beam conditioning and study using the 0-deg BD became impossible.

In order to avoid such troubles, we decided to develop a beam window protection system as quickly as possible. To this end, we have customized the particle counter used to supervise the accelerated-particle amount of the accelerator in J-PARC. In a short time, we have succeeded in developing and implementing a system that meets the performance required to protect the beam window.

BEAM WINDOW DAMAGE FOR 0-DEG BEAM DUMP

Beam Window For Beam Dump

The beam window is located upstream of the BD (Figure 1). It is made of Ni, which has a relatively high thermal conductivity, high temperature and mechanical strength. As a countermeasure against damage due to pressure differences, it has a mirror-plate (domed) shape. In addition, it has a thickness of 0.38 mm to reduce heat generation.

An injected beam with the following parameters is considered within tolerance based on temperature evaluation of the beam window:

(i) 50 mA, 100 µs length, no-chop, 2.5 Hz,
(ii) 50 mA, 500 µs length, no-chop, 1 shot only.

In addition, it is also known that (i) is a parameter set with a sufficient margin.

On the other hand, when the beam is injected to the BD, a chopped beam must be used in terms of beam loss. Here, from the actual measurement value, we know that the particle number of the chopped beam is less than 80% of the no-chop beam.

Thus, in the Linac, the beam tolerance has been set to (iii) when performing beam conditioning or study by injecting the beam into a BD.

(iii) 50 mA, 100 µs length, chopped, 3 Hz.

$$(3\ \text{Hz} \times 80\ \% = 2.4\ \text{Hz} < 2.5\ \text{Hz})$$

However, the need to install the beam window protection system was overlooked, because no trouble had been incurred by only confirming the beam parameters.

Beam Window Damage

A beam scraper baking was performed in the beam study of Linac for about a week starting in October 2018.

For a standard beam study, the parameters are a current 50 mA, beam length of 50 or 100 µs, and repetition rates of 1 or 2.5 Hz (< 3 Hz). On the other hand, this baking is performed by inserting scrapers into the beam line, for which parameters up to a current of 50 mA, beam length of 500 µs, and repetition rate of 25 Hz is used [2].

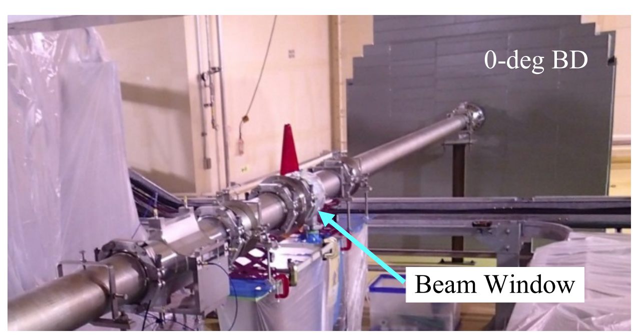

Figure 1: Location of beam window.

† takahashi.hiroki@jaea.go.jp

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In this study, the destination of the beam is set to the 0-deg BD, but beam incidence on this BD is prevented by setting the chopper performance to its maximum [3]. Therefore, confirmation of beam parameters, including the chopper function, is very important.

The procedure before and after the scraper baking test is as follows.

・At the beginning of this study:

Change the beam parameters after setting the chopper performance to its maximum.

・At the end of this study:

Set the chopper performance to its normal state (or OFF) after setting the beam parameters to within tolerances (e.g. 100 μs, 2.5 Hz)

However, due to multiple human errors, another beam study was started without "end procedure of baking study" having been performed. As such, a beam of 50 mA, 500 μs, and 25 Hz was injected to the 0-deg BD for about 1 second, and the beam window was broken (a hole of 12 mm in diameter was made). Thus, the degree of vacuum of the beam line for the 0-deg BD deteriorated.

Afterwards, countermeasures were employed to seal the 0-deg BD beam line from the atmosphere with the gate valve and etc, thereby avoiding a situation in which beam operation became impossible. However, the inability to use the 0-deg BD was a hindrance to beam conditioning and study. It was also necessary to prevent the same trouble from happening again.

Therefore, by the time the beam window was replaced (a few months later), we had to develop and implement a beam window protection system.

BEAM WINDOW PROTECTION SYSTEM

Requirements For The Beam Window Protection System

Based on temperature evaluation and the parameters for standard beam study, the developed beam window protection system must have a beam-inhibiting function (i.e., output the interlock signal) via machine protection system (MPS) when the following eventualities occur:

(1) a beam exceeding 100 μs length and chopped is injected, or

(2) beams corresponding to 100 μs length and chopped are injected with repetition rate of over 3 Hz.

By function (2), it is possible to protect the window from a beam that would not be included in (1) but occurs repetitively quickly (for example, 50 μs length, 10 Hz). Also, as a prerequisite for implementing functions (1) and (2), the function (3) is indispensable:

(3) elimination of beam measurement failure (measurement missing)

Particle Counter

Particle counters are used to supervise the beam power (accelerated-particle amount) of the J-PARC accelerator. These are therefore very important devices for safety systems that measure the particles in all 25 Hz beams.

Therefore, the particle counter monitors gate signal for a current transfer (CT) and eliminate the beam measurement failure (If a measurement missing is detected, the interlock signal is output). The picture of particle counter and the outline of signal flow between particle counter and CT are shown in Figs. 2 and 3.

Then, to realize the required function (3) within a few months, we decided to develop this system using the existing particle counter to measure the number of particles (CT-integrated value) per beam in all 25 Hz and to calculate the number of particles per hour. This counter inhibits the beam via MPS and personnel protection system before the integrated value exceeds the allowable one (limiting value). Therefore, it is not able to apply the original logic of the existing particle counter to this system.

Function Of The Beam Window Protection System

The logic component of the particle counter is implemented by a PLC ladder that runs in cycles of several millisecond. Thus, by designing and developing the logic for the beam window protection system and incorporating it into the PLC ladder, the required functions for this system are implemented.

First, the number of particles per beam at 25 Hz is monitored by the logic of function (1), and the MPS (interlock) signal is output if this number exceeds the threshold. Next, the movement-integrated value of the number of particles for one second (a total of 25 beams) is calculated by the logic of function (2), and the MPS signal is output if the value exceeds a threshold. After implementing these logics in the beam window protection system, we performed a threshold parameter search and a performance test using actual beams.

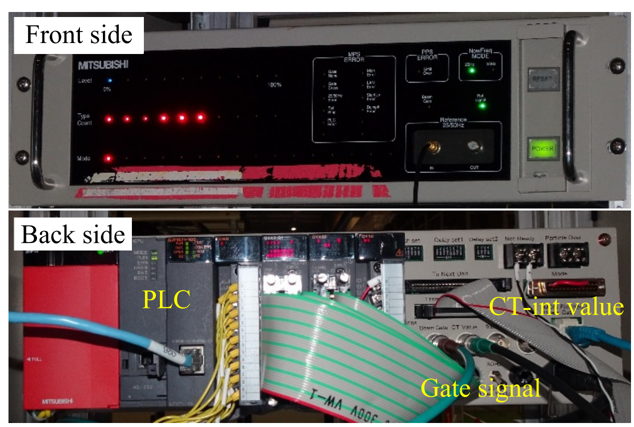

Figure 2: Picture of particle counter.

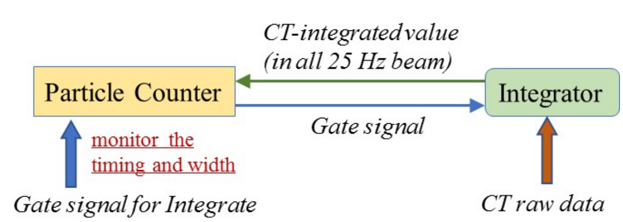

Figure 3: Signal flow related particle counter.

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Threshold Parameter Search

Performing threshold parameter searches and performance tests on beams injected to the 0-deg BD involves a high risk. Therefore, we performed then with the beam injected to the RCS.

First, we decided to use both measurement signals from a CT(a) installed in the 0-deg BD section and a CT(b) installed before the BD section. A CT(a) measures only the beam to the BD, and CT(b) can measure the beam injected to the RCS. (Figure 4 shows the location of CTs). Then, by measuring the same test signal with each CT (a) and CT (b), we could obtain the conversion factor from CT (b) to CT (a).

Next, CT (b) was connected to the beam window protection system and the parameter search for function (1) was performed using the beam injected to the RCS. Then, using the beam of "50 mA, 100 µs length, chopped, 2.5 Hz repetition rate", threshold parameter was determined by searching the boundary of MPS signal output/non-output.

Similarly, the threshold parameter of function (2) was also determined.

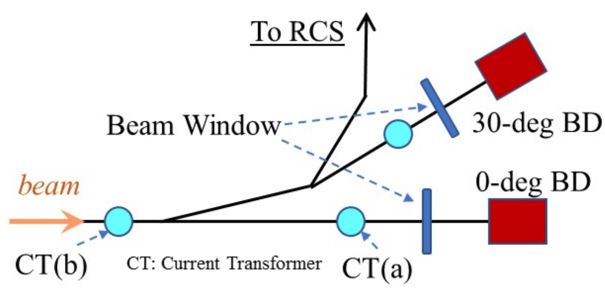

Figure 4: Location of CTs for parameter search

Performance Test

As a test of function (1), the results of the beam length of 110 µs are shown in Fig. 5. From this figure, it is found that the MPS signal is output 9 ms after a CT-integrated value of 110 µs beam is input. Thus, the function (1) for the one-shot beam is implemented in this system.

Next, for function (2), the results in the case of beam in repetition rate of 25 Hz are shown in Fig. 6. Since the threshold is set to output the MPS signal when it exceeds 3 Hz, it is desirable to output it after four beams have been measured. Figure 6 shows the function is as expected. Furthermore, the same result is obtained also in case of repetition rate of 5 Hz. Thus, we evaluate the beam window protection system developed this time is fully satisfactory as an initial system.

Then, by the conversion factor CT(b) to CT(a), we calculated the threshold parameters for CT (a) from the obtained parameters for CT(b). And, the parameters for CT(a) were set in the system, and it was started operation as a beam window protection system for 0-deg BD. Immediately after the start of the operation, although the beam was within tolerances, the MPS signal was output several times. Thus, although the parameter was adjusted a few times, no problems has occurred after that.

Future Plan

At present, we are considering improvements to the beam window protection system is able to make continuous measurement (about 1 MS/s) on a beam, rather than measurement for each beam. In function (1), this improvement makes it possible to inhibit in the middle of one beam. For example, when a beam length of 500 µs is injected, it will become possible to inhibit beam at about 100 µs. And, we also expect that similar improvement is made for function (2).

CONCLUSION

We developed a protection system to prevent the beam window from breaking again. As this system required quick implementation, we developed it based on the existing particle counter. Thus, development was completed two months after beam window cracked, and tests confirmed that the function satisfied the requirements. At present, in order to improve performance, we are considering upgrading to a system that can measure a beam continuously. This upgrade may allow construction of a protection system that minimizes the damage caused by the beam under erroneous operation.

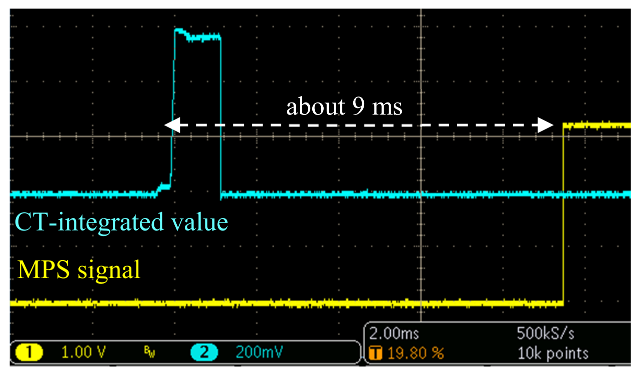

Figure 5: Result of performance test for function (1). (case of 110 µsec length beam is injected).

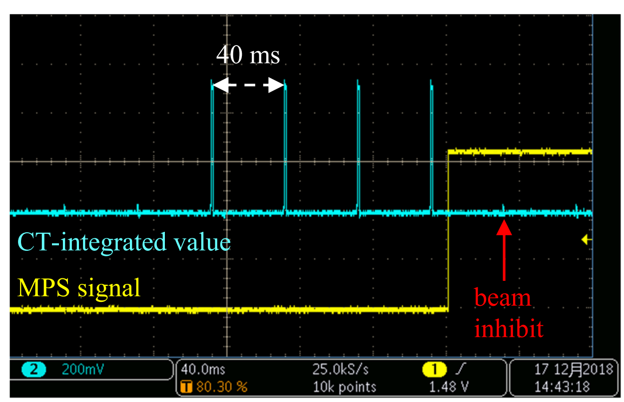

Figure 6: Result of performance test for function (2). (case of beam repetition at 25 Hz).

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